

Geologic Resource Evaluation Scoping Summary

Organ Pipe Cactus National Monument, Arizona

This report highlights a geologic resource evaluation scoping session that was held at Organ Pipe Cactus National Monument on January 25–26, 2006. The NPS Geologic Resources Division (GRD) organized this scoping session in order to view and discuss the monument’s geologic resources, address the status of geologic maps and digitizing, and assess resource management issues and needs. In addition, on January 24, 2006, GRE staff met at the Arizona Geological Survey to discuss cooperative efforts in national parks in Arizona, including Organ Pipe Cactus National Monument. Participants at the meeting at Organ Pipe Cactus included GRD staff, park staff, staff from the Sonoran Desert Network, and cooperators from the US Geological Survey, Arizona Geological Survey, Northern Arizona University, and Colorado State University (table 1).

Table 1. Scoping Session Participants

Name	Affiliation	Phone	E-mail
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Wednesday, January 25, involved a welcome and introduction to the Geologic Resource Evaluation (GRE) Program, including the status of reports and map products. The morning’s discussion focused on map coverage of the monument and other “quadrangles of interest” in the vicinity of the monument. In addition, Gordon Haxel (USGS-Flagstaff) presented a colorful history of the geologic mapping at Organ Pipe Cactus National Monument and an overview of the geologic setting. Bruce Heise facilitated a group discussion regarding the geologic processes and features at the monument. In the afternoon, attendees participated in a field trip led by Gordon Haxel along the Ajo Mountain Loop Drive. Highlights included the Ajo volcanic field, Childs Latite, debris flows in channel deposits, and desert pavement.

Participants continued in the field on **Thursday, January 26**. Gordon Haxel and Steve Richard (Arizona Geological Survey) organized stops that highlighted the mid-Tertiary extension that occurred in the region. They identified and discussed the Locomotive Conglomerate (with 1.4-billion-year-old clasts of granite), which was deposited in the basin during this extension event. This rock unit is interbedded with Ajo volcanics.

Overview of Geologic Resource Evaluation Program

Geologic features and processes serve as the foundation of park ecosystems and an understanding of geologic resources yields important information for park decision making. The National Park Service

(NPS) Natural Resource Challenge, an action plan to advance the management and protection of park resources, has focused efforts to inventory the natural resources of parks. Ultimately, the inventory and monitoring of natural resources will become integral parts of park planning, operations and maintenance, visitor protection, and interpretation.

The Geologic Resource Evaluation (GRE) Program, which the NPS Geologic Resources Division administers, carries out the geologic component of the inventory. Staff associated with other programs within the Geologic Resources Division (e.g., the abandoned mine land, cave, coastal, disturbed lands restoration, minerals management, and paleontology programs) provide expertise to the GRE effort. The goal of the GRE Program is to provide each of the identified “natural area” parks with a digital geologic map, a geologic resource evaluation report, and a geologic bibliography. Each product is a tool to support the stewardship of park resources and is designed to be user friendly to non-geoscientists.

GRE teams hold scoping meetings at parks to review available data on the geology of a particular park and to discuss specific geologic issues affecting the park. Park staff is afforded the opportunity to meet with park geology experts during these meetings. Scoping meetings are usually held for individual parks although some address an entire Vital Signs Monitoring Network.

Bedrock and surficial geologic maps and information provide the foundation for studies of groundwater, geomorphology, soils, and environmental hazards. Geologic maps describe the underlying physical framework of many natural systems and are an integral component of the physical inventories stipulated by the National Park Service in its Natural Resources Inventory and Monitoring Guideline (NPS-75) and the 1997 NPS Strategic Plan. The NPS geologic resource evaluation is a cooperative implementation of a systematic, comprehensive inventory of the geologic resources in National Park System units by the Geologic Resources Division; the Inventory, Monitoring, and Evaluation Office of the Natural Resource Program Center; the US Geological Survey; and state geological surveys.

For additional information regarding the content of this summary, please consult the NPS Geologic Resources Division, located in Denver, Colorado. Up-to-date contact information is available on the GRE Web site at <http://www2.nature.nps.gov/geology/inventory/>.

The objectives of the geologic resource evaluation scoping meetings are as follows:

- To identify geologic mapping coverage and needs
- To identify distinctive geologic processes and features
- To identify resource management issues
- To identify potential monitoring and research needs

Outcomes of the scoping process include the following items:

- A scoping summary (this document)
- A bibliography
- A digital geologic map
- A geologic resource evaluation report

The scoping process includes a site visit with local experts, evaluation of the adequacy of existing geologic maps, and discussion of park-specific geologic management issues. The emphasis of scoping is not to routinely initiate new geologic mapping projects but to aggregate existing information and identify where serious geologic data needs and issues exist in the National Park System.

Status of Scoping and Products

As of April 2006, the NPS Geologic Resources Division had completed the scoping process for 160 of 272 “natural resource” parks. Staff and partners of the GRE Program have completed digital maps for 68 parks. These compiled geologic maps are available for downloading from the NR-GIS Metadata and Data Store at <http://science.nature.nps.gov/nrdata>. The US Geological Survey, various state geological surveys, and investigators at academic institutions are in the process of preparing mapping products for 42 parks. Bibliographies for 272 parks are currently undergoing data validation and updates. Writers have completed 22 GRE reports with 18 additional reports to be completed by the end of fiscal year 2006.

Geologic Maps for Organ Pipe Cactus National Monument

During the scoping session on January 25, 2006, Tim Connors (GRD) presented a demonstration of some of the main features of the digital geologic map model used by the GRE Program. This model incorporates the standards of digitization set for the GRE Program. The model reproduces all aspects of a paper map, including notes, legend, and cross sections, with the added benefit of being GIS compatible. GRE staff members digitize maps using ESRI ArcView/ArcGIS format with shape files and other features, including a built-in help file system to identify map units.

Parks in Inventory and Monitoring Network use “quadrangles of interest” mapped at one or more of the following scales: 7.5' × 7.5' (1:24,000), 15' × 15' (1:62,500), or 30' × 60' (1:100,000). Often for simplicity, geologic map makers compile maps at 1:100,000 scale (30' × 60'), which provides greater consistency and covers more area. However, for the purpose of geologic resource evaluations, GRE staff would like to obtain digital geologic maps of all identified 7.5-minute (1:24,000-scale) quadrangles of interest for a particular park. The geologic features mapped at this scale are equivalent to the width of a one-lane road. The quadrangles of interest for Organ Pipe Cactus are shown in figure 1 and listed in table 2. The contents of this document reflect what participants know about the published geologic maps as of April 2006.

The original 40 quadrangles of interest (scale 1:24,000) for Organ Pipe Cactus National Monument are as follows: Cimarron Peak, Coffeepot Mountain, Burro Gap, Ajo North, Childs Mountain, Growler Peak, West of Growler Peak, Hickiwan, Gakolik Mountains, Sikort Chuapo, Ajo South, Chico Shunie, Temporal Pass, Saguaro Gap Well, West of Wahak Hotrontk, Hotason Vo, Gunsight, Armenta Well, Bates Well, Palo Verde Camp, North of Agua Dulce Mountain, West of Pisinimo, Gu Vo, Mount Ajo, Tillotson Peak, Kino Peak, Pozo Nuevo Well, Agua Dulce Mountains, Chupan Mountain, Pia Oik, Diaz Peak, Lukeville, West of Lukeville, Quitobaquito Springs, West of Quitobaquito Springs, Bailey Peak, Menagers Lake, Blankenship Well, South of Lukeville, and South of Bailey Peak, which are situated on the Ajo, Cabeza Prieta Mountains, Lukeville, and Quitobaquito Hills 30' × 60' sheets (see figure 1 and table 2). However, during the January 25, 2006, scoping meeting, participants discussed the relevance of obtaining digital geologic data for all these quadrangles of interest and determined that—pending additional analysis by park staff—adequate map coverage for the monument consists of 18 quadrangles of interest (scale 1:24,000): Hotason Vo, Gunsight, Armenta Well, Bates Well, Palo Verde Camp, Gu Vo, Mount Ajo, Tillotson Peak, Kino Peak, Pozo Nuevo Well, Pia Oik, Diaz Peak, Lukeville, West of Lukeville, Quitobaquito Springs, Menagers Lake, Blankenship Well, and South of Lukeville.

Organ Pipe Cactus National Monument currently has a digital geologic map with metadata: *Geological Reconnaissance at Organ Pipe Cactus National Monument, Arizona*, which was mapped at scale 1:62,500 and later digitized at scale 1:24,000. This map appears in the GRE database as GMAP 3707. *Geological Reconnaissance at Organ Pipe Cactus National Monument, Arizona* (GMAP 3707) does not completely cover six of the 18 previously mentioned quadrangles of interest: Quitobaquito Springs, West of Lukeville, Lukeville, South of Lukeville, Blankenship Well, and Menagers Lake. Nonetheless, park staff would like digital geology for these entire quadrangles.



Figure 1. Quadrangles of interest for Organ Pipe Cactus National Monument, Arizona. Names in black indicate 7.5-minute quadrangles (scale 1:24,000); names in blue indicate 30-minute by 60-minute quadrangles (scale 1:100,000). Background shading indicates United States (yellow) and Mexico (blue). Green outline indicates the boundary of the monument.

The authors of GMAP 3707 are Andrea C. Eddy, Gordon B. Haxel, Dan J. May, Robert J. Miller, Don W. Peterson, and Richard M. Tosdal. According to the digital map metadata, the University of Arizona, Advanced Resource Technology Program, School of Renewable Natural Resources in Tucson (contact: Phil Guertin, 520-621-1723) digitized these data from photo-Mylar of USGS quadrangles. The work was contracted through a cooperative agreement between the University of Arizona, the Cooperative Park Studies Unit, and Organ Pipe Cactus National Monument. Tom Potter (former GIS specialist at Organ Pipe Cactus National Monument, now with the USDA Forest Service; 928-443-8031, thomaspotter@fs.fed.us) tested these data in 1991. In 2004, Ifer McCollum (formerly with the NPS Intermountain Region, now with the private sector; iferrocks@hotmail.com) converted the dataset from a pre-7.0 version coverage to its current coverage. Sue Rutman (GIS specialist, Organ Pipe Cactus National Monument, sue_rutman@nps.gov, 520-387-6849 x. 7115) supplied the metadata used to update the draft of this scoping summary (Sue Rutman, personal communication, April 14, 2006).

At the time of the scoping meeting, participants did not know the whereabouts of the original photo-Mylar. However, participants deem finding this information a significant step for verifying the data of the digital files and deciding what additional work needs to be done. Post-meeting correspondence reinforces the need to verify the original map, which staff at Organ Pipe is now using in the park's GIS. Ifor McCollom, who converted the digital data to the NPS model, expressed concern over the data stating "Personally, I would be dubious about the quality of the original mapping and on the methods for making it a digital GIS dataset." She never saw any hardcopy media of the original maps (Ifor McCollum, formerly National Park Service, now private sector; written communication, April 18, 2006). During the meeting, Andy Hubbard (Sonoran Desert Network) and Peter Holm (Organ Pipe Cactus National Monument) said they would check their respective libraries and files for this original map. GRE staff may need to ask USGS staff (contact: Bob Miller, rjmiller@usgs.gov, 650-329-5407) to check files in Menlo Park. In addition, the aforementioned contacts listed in the digital map metadata may also be leads for how to track down the original data.

Table 2. Quadrangles of Interest for Organ Pipe Cactus National Monument

Quadrangle of interest	Map citation	Paper	Digital
<i>GRE Plan: Digitize USGS paper map to GRE digital format</i>			
Hotason Vo Gunsight Gu Vo Mount Ajo	Tosdal, R.M., Peterson, D.W., May, D.J., Le Vegue, R.A., and Miller, R.J., 1986, Reconnaissance geologic map of the Mount Ajo and part of the Pisinimo quadrangles, Pima County, Arizona: US Geological Survey Miscellaneous Field Studies Map MF-1820, scale 1:62,500 (GMAP 1460).	Yes	No
<i>GRE Plan: Digitize USGS paper map to GRE digital format</i>			
Diaz Peak Blankenship Well	Beikman, H.M., Haxel, G.B., and Miller, R.J., 1995, Geologic map of the Tohono O'Odham Indian Reservation, southern Arizona: US Geological Survey Miscellaneous Geologic Investigations Map I-2017, scale 1:125,000 (GMAP 1462).	Yes	No
<i>GRE Plan: Convert IMR digital format to GRE digital format</i>			
Bates Well Palo Verde Camp Tillotson Peak Kino Peak Pozo Nuevo Well Pia Oik Armenta Well <i>Parts of</i> Lukeville West of Lukeville Quitobaquito Springs Menagers Lake South of Lukeville	Eddy, A.C., Haxel, G.B., May, D.J., Miller, R.J., Peterson, D.W., and Tosdal, R.M., 1988 [digitized in 1991; converted in 2004], Geological reconnaissance at Organ Pipe Cactus National Monument, Arizona [unpublished]: US Geological Survey [and National Park Service], scale 1:62,500 [digital data—scale 1:24,000] (GMAP 7307).	Unknown	Yes

Notes: The maps in table 2 are bedrock geology and do not include surficial deposits.

In order to accomplish the goal of providing resource managers at Organ Pipe Cactus with digital geologic data (bedrock and surficial) for the 18 quadrangles of interest, a team of investigators from Northern Arizona University (see table 1) and Gordon Haxel (USGS-Flagstaff) will work on finalizing a more detailed, compiled bedrock map of the monument and submitting a proposal to the NPS Geologic Resources Division.

Investigators have completed several geologic maps of various vintages and scales in the Organ Pipe region. These will serve as the starting point for completing a compiled bedrock map. These sources are as follows:

Overview of entire monument

Eddy, A.C., Haxel, G.B., May, D.J., Miller, R.J., Peterson, D.W., and Tosdal, R.M., 1988 [digitized in 1991; converted in 2004], Geological reconnaissance at Organ Pipe Cactus National Monument, Arizona [unpublished]: US Geological Survey [and National Park Service], scale 1:62,500 [digital data—scale 1:24,000] (GMAP 7307).

Northeastern portion of monument

Tosdal, R.M., Peterson, D.W., May, D.J., Le Vegue, R.A., and Miller, R.J., 1986, Reconnaissance geologic map of the Mount Ajo and part of the Pisinimo quadrangles, Pima County, Arizona: US Geological Survey Miscellaneous Field Studies Map MF-1820, scale 1:62,500 (GMAP 1460).

Eastern portion of monument

Beikman, H.M., Haxel, G.B., and Miller, R.J., 1995, Geologic map of the Tohono O'Odham Indian Reservation, southern Arizona: US Geological Survey Miscellaneous Geologic Investigations Map I-2017, scale 1:125,000 (GMAP 1462).

Extreme northwestern portion of monument/northwestern quadrangles of interest

Gray, F., Miller, R.J., Peterson, D.W., May, D.J., Tosdal, R.M., and Kahle, K., 1985, Geologic map of the Growler Mountains, Pima and Maricopa Counties, Arizona: US Geological Survey Miscellaneous Field Investigations MF-1681, scale 1:62,500 (GMAP 1459).

Additional coverage at coarse scale

Kahle, K., Conway, D., and Haxel, G., 1978, Preliminary geologic map of the Ajo 1 degree by 2 degree quadrangle, Arizona: US Geological Survey Open-File Report OF-78-1096, scale 1:250,000 (GMAP 1465).

Morrison, R.B., 1984, Late Pliocene and Quaternary geology, Ajo quadrangle: Arizona Bureau of Geology and Mineral Technology Open-File Report OFR-84-01, scale 1:250,000 (GMAP 1466).

Morrison, R.B., 1984, Late Pliocene and Quaternary geology, Lukeville and Sonoyta [quadrangles]: Arizona Bureau of Geology and Mineral Technology Open-File Report OFR-84-03, scale 1:250,000 (GMAP 1467).

Investigators from Northern Arizona University should use the map by Beikman and others (GMAP 1462) to augment coverage of the Diaz Peak and Blankenship Well quadrangles. They should use the map by Tosdal and others (GMAP 1460) to augment coverage of the Hotason Vo, Gunsight, Gu Vo, and Mount Ajo quadrangles.

Since the scoping meeting in January 2006, park staff expressed an interest in a geologic map showing carbonate-bearing units at the monument (Mary Kralovec, Organ Pipe Cactus National Monument, written communication, March 16, 2006).

With respect to surficial geology, the existing maps published by the Arizona Geological Survey are probably too coarse to be of use for resource management (i.e., GMAP 1466 and 1467 [see references below]). Park staff will identify several quadrangles where completed surficial mapping is of highest priority (e.g., high-use corridors, areas with facilities, and wildlife passages). Participants discussed the Arizona Geological Survey being the lead on surficial mapping for the monument, initially mapping high-

priority areas at scale 1:24,000 with “reconnaissance mapping” of lower priority areas. GRE staff will cooperate with the Arizona Geological Survey to set up a work plan and arrange funding.

Numerous aerial photos, available through the Sonoran Desert Network, may be useful for surficial mapping. For instance, Peter Warren, an ecologist with The Nature Conservancy (520-622-3861), produced a vegetation map for the monument in 1978 using aerial photographs and ground-truthing; since that time Warren has been involved in a number of other ecological investigations at Organ Pipe Cactus. In the late 1990s and into the early 2000s, the “Warren method” for vegetation mapping was extended from Organ Pipe Cactus National Monument onto adjacent DOI lands (i.e., Bureau of Land Management and Cabeza Prieta National Wildlife Refuge). The intent was to get detailed vegetation mapping to allow evaluation of pronghorn habitat, as well as providing a continuous, comparable vegetation layer for Organ Pipe, BLM, and Cabeza Prieta. Later use of the “Warren method” (e.g., by Jim Malusa and Bill Halvorson at USGS–University of Arizona) varied in that more recent mapping used near-IR digital orthoquad maps instead of true-color aerial photos. In addition, IKONOS satellite imagery may be more useful than aerial photographs; staff at Organ Pipe Cactus National Monument currently has such imagery for the entire monument (Mary Kralovec, Organ Pipe Cactus National Monument, written communication, March 16, 2006), which would be available for use by investigators from Northern Arizona University, Arizona Geological Survey, and US Geological Survey (Sue Rutman, Organ Pipe National Monument, personal communication, April 17, 2006).

According to participants, satellite imagery and aerial photos would be more than adequate for mapping 1:24,000-scale geologic features. Aerial photos would help map areas of the monument that cannot be ground-truthed for reasons of safety in the current political/social climate. In particular, participants discussed completing the geologic coverage of certain quadrangles of interest along the southern boundary of the monument, including adjacent areas of Mexico. However, during the review process of this summary, Jason Raucci emphasized that the ability to complete new mapping of areas south of the international border will depend on safety. Unless the security situation changes between now and when mapping is completed, investigations from Northern Arizona University will be limited to digitizing available maps from published articles about the region (primarily Campbell and Anderson, 2003—see “References for ‘Unique Geologic Features’ Section”), and perhaps extrapolating these data using air photos. Hence, these southern quadrangles will likely not be mapped to the same standard as the other more-northern quadrangles (Jason Raucci, Northern Arizona University, written communication, March 21, 2006).

Geologic Resource Evaluation Report

Geologic Resource Evaluation reports include sections about geologic resources of concern for management (referred to as “issues”), geologic features and processes, the park’s geologic history, a map unit properties table that highlights the significant features and resource concerns for each map unit in the park, references (different from the bibliography), and various appendices (e.g., map graphics and scoping report). This scoping summary will serve as a starting point for information to be included in the GRE report for Organ Pipe Cactus National Monument.

Geologic Features, Processes, and Issues at Organ Pipe Cactus National Monument

The scoping session at Organ Pipe Cactus National Monument provided the opportunity to capture a list of geologic features and processes operating in the monument, which will be highlighted and expanded in the GRE report. Some of these features and processes may be of concern for resource managers. The “top three” issues of management concern identified during the scoping session were (1) streams and flooding, (2) tinajas, and (3) bajadas. The first is of concern because of the potential to transport sediment, particularly across roads. The second and third are significant because of their connection to ecology and the general lack of surface water in the monument. In addition, volcanic features and processes are of particular interest for interpretation and education.

Streams and Flooding

Organ Pipe Cactus National Monument contains numerous washes that experience intermittent flow during wet periods. In addition, with an estimated three inches per hour, summer storms periodically cause flooding events. An issue for park managers is “stream capture” by roads during these flooding events. Undoubtedly, Holocene-age flood deposits will be a significant unit of the monument’s future surficial map, which in turn would help locate potentially hazardous areas during floods.

Tinajas

Natural potholes, called tinajas, are the most significant source for surface water in the monument. Once upon a time, ranchers did carve out some additional potholes for watering livestock; however, tinajas are natural features. Tinajas form over time through fluvial processes that scour out the massive, homogeneous, non-fractured bedrock. They appear to form along mathematically predictably spacing, though no one has conducted any formal studies that look at distribution. Tinajas primarily occur in areas where bedrock is exposed at the surface, typically in the massive rhyolite units and possibly the Childs Latite. A geologic map showing the locations of tinajas would be very useful for resource management, particularly because they are important sources of water for wildlife, as the name of one tinaja, “Wild Horse Tank,” indicates. Participants discussed whether tinajas serve as “gathering spots” for illegal immigrants—another reason for mapping these features; however, no study has made any such connection. Some tinajas are so large that they support their own riparian vegetation. In addition, large tinajas have been known to trap animals that enter them for water or vegetation (e.g., Alamo Canyon “snake trap”).

Neither park nor Sonoran Desert Network staffs have conducted an inventory of tinajas but suspect that hundreds or thousands of these features occur in the monument. Park and network staffs would be very interested in finding external funding for an inventory of these because of their significance.

Bajadas

Alluvium covers approximately 70% of Organ Pipe Cactus National Monument. A significant alluvial feature is bajadas—coalescing alluvial fans that occur at the base of hills in areas that are subject to periodic flash floods during thunderstorms. These features are very common around the margins of the sedimentary basins of the Basin and Range of southwestern United States and northern Mexico; Organ Pipe Cactus preserves some classic examples.

The continuum of rocky slopes, bajada, and fine-grained material on the valley floors constitute a significant natural feature that is important for both plant and animal diversity. Active alluvial fans, many in the Valley of the Ajo, support dense stands of vegetation important to wildlife. Generally where slopes are less than 1.5°, sheet flow creates two-phase plant communities that may be important to pronghorn habitat (Mary Kralovec, Organ Pipe Cactus National Monument, written communication, March 16, 2006). As such, future soil and vegetation mapping in the monument will focus on bajadas. Park and network staffs will participate in a soil scoping session with Pete Biggam, NPS Soil Scientist, in March 2006. Investigators will use grain size, soil depth, and vegetation to describe the bajada system. The bajada–valley floor zone (i.e., base of alluvial fans) is an area of increased moisture, where plants often concentrate. If the water is close enough to the surface, springs and seeps form at this level. Past and present cultures used these areas for farming.

A complex of springs (Quitobaquito springs) provides water to Quitobaquito pond. A topographic divide causes half the springs in the monument to flow toward the south and half to flow north.

Volcanic Features and Processes

Organ Pipe Cactus National Monument includes part of the ancient Pinacate volcanic field, which covers more than 1,900 square miles (4,920 km²). Distinctive rocks of this volcanic field are displayed along the steep mountain front of the northern Ajo Range in the monument. These volcanic rocks are rhyolite and tuff. Opal and silica veins occur in the rhyolite. As discussed in *A Guide to the Geology of Organ Pipe Cactus National Monument and Pinacate Biosphere Reserve*, rhyolite formed from short, thick, bulbous lava flows during relatively quiet, non-explosive eruptions. Being relatively rich in silica, these rhyolite flows were viscous, which resulted in flowage of only a few miles from their eruptive vents. These flows are representative of the entire Ajo Range, which is a testament to high viscosity. The rhyolite flows appear as massive, darker rocks in the mountain faces. Lighter-colored layers of tuff separate the rhyolite flows. Tuff is composed of rhyolitic volcanic ash and small rock fragments ejected during shorter, explosive eruptions. The sequence of flows is more than 2,000 feet (610 m) thick, highlighting a brief but intense burst of volcanic activity between 16 and 18 million years ago. The most recent eruptions of the field occurred during the 1600s about 400 miles (250 km) southwest of the monument. Present-day eruptions from this volcanic field would result in ash or cinders being deposited in the monument.

Participants also discussed the following features and processes:

Caves and Karst

At least two units of carbonate rock occur within Organ Pipe Cactus National Monument. However, given the size of these carbonate-rock bodies, the occurrence of caves and karst in these rocks is unlikely (Gordon Haxel, USGS-Flagstaff, written communication, February 13, 2006). According to Gordon Haxel these units are as follows:

1. A single small (tens of meters) fault slice occurs northwest of Pinkley Peak. This fault slice is much too small to be shown on the page-size geologic map of Haxel and others (1984) (see figure 7 in reference below) but will, of course, appear on a larger scale geologic map.

Haxel, G.B., Tosdal, R.M., May, D.J., and Wright, J.E., 1984, Late Cretaceous and early Tertiary orogenesis in south-central Arizona—thrust faulting, regional metamorphism, and granitic plutonism: *Geological Society of America Bulletin*, v. 95, p. 631–653.

2. Some thin (<1 meter to a few meters) beds (possibly transposed) or layers of calcite marble within the Jurassic metasedimentary rocks.

While the monument may not have caves in carbonate rocks, it does host many small caves of volcanic origins. These caves are significant for wildlife, archaeology, and fossil pack-rat middens. “Caliche caves” are also important for wildlife habitat (Mary Kralovec, Organ Pipe Cactus National Monument, written communication, March 16, 2006).

In addition, carbonate rocks (i.e., limestone, dolostone, and derivation marble) occur north of the monument, near Scarface Mountain. (Participants saw these on the field trip.) The formations are Martin and Escabrosa. Additionally, the Abrigo Formation may also contain some impure carbonate.

Eolian (Windblown) Features and Processes

Eolian processes are very important in southwestern Arizona for creating characteristic features such as desert pavements and sand dunes. Wind erosion is driven by denudation of vegetation, for example, on dirt roads and mine tailings. During surficial mapping of the monument, the Arizona Geological Survey will map eolian deposits such as dunes and loess.

Geothermal Features and Processes

The aquifer underlying Organ Pipe Cactus National Monument has increased temperatures. However, these “warmish” temperatures are not high enough to warrant potential development of waters that could affect park resources.

Hillslope Features and Processes

Though not a major issue for park managers, periodic rockfall occurs throughout the monument. Generally speaking, when softer rock units underlie more resistant volcanic units, rockfall is likely. Participants identified the area below Twin Peak as a potentially hazardous zone; park housing and the water tank are located in this area. In addition, participants discussed the possibility of sonic booms causing rockfall, as well as increased precipitation during hurricanes facilitating the formation of talus cones, which are common mass-wasting landforms in the monument.

Minerals, Mining, and Disturbed Lands

The Senita Basin granite consists of approximately equal amounts of quartz, alkali feldspar (rich in potassium and sodium), and plagioclase feldspar. The granite also contains small amounts of several other minerals: biotite and muscovite micas and small crystals of garnet. A few of the larger quartz veins bear minerals containing lead, silver, copper, gold, and zinc. In the late 1800s and early 1900s, prospectors developed small mines in some of these mineral-bearing quartz veins. Three old mines—Victoria, Lost Cabin, and Martinez—are located along the margins of the granitic pluton (on the Bates Well quadrangle). A safety inspector (volunteer) annually checks these mines.

During the intrusion that deposited the Senita Basin granite (Laramide age), conditions were just right to produce an abundance of extremely rich copper ores that fueled Arizona’s mining industry. Extensive exploration and drill holes in the northern part of monument attest to potential development for copper deposits. There is no economic interest in the small mines in the monument at present. However, if copper prices rise in the future, interest in mining north of the Bates Well quadrangle could occur. In the event of a “boom,” discussions between the Bureau of Land Management and National Park Service would be significant for the protection of park resources.

During the field trip on January 26, a brief discussion ensued about the pit, tailings, and dump piles of the “Ajo Mine” (also known as the New Cornelia Pit), which cover approximately two square miles at the edge of Ajo, Arizona, north of the monument. According to Steve Richard (Arizona Geological Survey), high carbonate content in the soils probably buffers the metals in the piles; moreover, groundwater flows north (away from the monument) and probably does not affect park resources.

In addition to the mineral specimens in the Senita Basin granite (i.e., lead, silver, copper, gold, and zinc) and rhyolite of the Ajo Range (i.e., opal and silica veins), Childs Latite is a distinctive and “showy” rock that occurs in the monument. Childs Latite represents a slightly earlier volcanic episode than the rhyolite of the northern Ajo Range. The name “Childs” comes from Childs Mountain near Ajo, Arizona, where geologists first described this rock. Large (0.5–1.5 inches [1–4 cm]) plagioclase crystals characterize this latite. During the January 25 field trip, participants noted that the distinctive “chunky” nature of the rock, once cut and polished, would result in a nice set of bookends; hence, collection of Childs Latite by “rock hounds” could be a minor concern for resource protection.

Paleontological Resources

During the scoping meeting, Gordon Haxel (USGS-flagstaff) showed a picture of a Tertiary conglomerate that contained fossils (e.g., shells, crinoid stems, and brachiopods). Haxel assumes that these fossils are rather insignificant; however, in post-meeting correspondence with Jason Kenworthy (GRD paleontology technician at George Washington Memorial Parkway, Virginia), this turned out to be the first documentation of fossils in a bedrock unit for Organ Pipe Cactus National Monument. Kenworthy

suspects that these fossils were from reworked Paleozoic cobbles (Jason Kenworthy, written communication, February 10, 2006).

In addition, Kenworthy pointed out the significance of a more-recent paleontological resource—packrat middens that contain pollen and arthropods. The materials in the packrat middens register dates from as recent as 30 years to as much as 14,000 years ago. Kenworthy provided numerous references on the subject. Additionally, he mentioned that Dr. Ken Cole (ken_cole@usgs.gov) of the USGS Colorado Plateau Research Station, Southwest Biological Science Center might be able to provide additional information. The references are as follows:

Davis, O.K., and Anderson, R.S., 1987, Pollen in packrat (*Neotoma*) midden—Pollen transport and the relationship of pollen to vegetation: *Palynology* v. 11, p. 185–198.

Hall, W.E., Van Devender, T.R., and Olson, C.A., 1990, Arthropod history of the Puerto Blanco Mountains, Organ Pipe Cactus National Monument, Southwestern Arizona, *in* Betancourt, J.L., Van Devender, T.R., and Martin, P. S., eds., *Packrat middens—The last 40,000 years of biotic change*: Tucson, University of Arizona Press, p. 363–379.

Van Devender, T.R., Toolin, L.J., and Burgess, T.L., 1990, The ecology and paleoecology of grasses in selected Sonoran Desert plant communities, *in* Betancourt, J.L., Van Devender, T.R., and Martin, P.S., eds., *Packrat middens—The last 40,000 years of biotic change*. Tucson, University of Arizona Press, p. 326–349

Van Devender, T.R., 1990, The vegetation and climate of Organ Pipe Cactus National Monument—The view from the ice age, *in* Bennett, P.S., Johnson, R.R., and McCarthy, M.M., eds., *Assessment of scientific information and activities at Organ Pipe Cactus National Monument Biosphere Reserve*: Tucson, University of Arizona, Cooperative National Park Resources Studies Unit (CPSU) Special Report 10.

Van Devender, T.R., 1987, Holocene vegetation and climate in the Puerto Blanco Mountains, Southwestern Arizona: *Quaternary Research*, v. 27, p. 51–72.

Seismic Features and Processes

The nearest active fault to the monument is the Salton Trough in southern California. The nearest, most-recent, significant earthquake occurred south of Douglas, Arizona, in 1986. In addition, magnitude 5–7 earthquakes occur regularly in the California’s Imperial Valley. Seismic activity that would affect the infrastructure in the monument is highly unlikely; however, the Arizona Geological Survey produced a seismic hazards map for Arizona, which may be of interest for park managers. Field investigations during future surficial mapping will also check for Pleistocene-age fault scarps, though none are presently known to occur.

Large-scale (10 to 100 meter) desiccation cracks that form polygonal patterns occur east and west of the monument. It is likely that they also occur in the basins in the monument. At this scale, they will be present on the future surficial map. These features could cause engineering impacts, that is, subsidence

Unique Geologic Features

Source: Gordon Haxel, written communication, March 6, 2006.

The two geologic “highlights” of Organ Pipe Cactus National Monument are the Ajo Range (see “Volcanic Features and Processes”) and the Quitobaquito thrust. The Quitobaquito thrust is part of the Mojave-Sonora megashear—a system of faults that places Precambrian gneisses and schists over

(younger) Jurassic plutonic rocks. It is a major sinistral strike-slip fault exposed near Sonoyta, Sonora (Campbell and Anderson, 2003). Examination of this significant deformation event has led investigators to describe the Jurassic setting of what is now Organ Pipe Cactus National Monument as geologically similar to present-day Los Angeles or New Zealand.

Organ Pipe National Monument is in the middle of a geologic controversy surrounding the Mojave-Sonora megashear. Researchers need to examine the Quitobaquito thrust, which occurs in the Quitobaquito Hills of the monument, in order to gather more data about this ductile thrust fault. Originally, researchers considered the Quitobaquito thrust to be a late Cretaceous or early Tertiary (“Laramide”) structure (Haxel and others, 1984; Tosdal and others, 1990) related to thrust faults of that age exposed in ranges to the east, for example, the Baboquivari thrust in the Baboquivari and Comobabi Mountains and Window Mountain Well in the Sierra Blanca (Beikman, 1995). Presumably, all of these thrust faults, like similar structures elsewhere in Arizona and adjacent southern California and northern Sonora, reflect crustal compression during the Laramide Orogeny.

In more recent research, however, Anderson and others (2005) argues that the Quitobaquito thrust is fundamentally a Jurassic structure, related to transpression along the Mojave-Sonora megashear. Nonetheless, some movement on the Quitobaquito thrust and accompanying minor thrust faults must have occurred after Late Cretaceous time, as mylonitic fabrics related to these faults locally are imposed upon the Late Cretaceous (U-Pb age) Aquajita Spring Granite. However, this relation leaves open the possibility that the major period of movement was Jurassic, with relatively minor reactivation of some faults in Laramide time.

Resolution of this controversy will require further study of critical evidence provided by igneous and metamorphic structures and fabrics exposed in the Quitobaquito Hills. Researchers have not reexamined these field relations since this controversy arose, and in fact have never systematically restudied the Quitobaquito thrust since the original mapping of the Quitobaquito Hills in 1980.

References for “Unique Geologic Features” Section

- Anderson T.H., Rodríguez-Castañeda, J.L., and Silver, L.T., 2005, Jurassic rocks in Sonora, Mexico—relations to Mojave-Sonora megashear and its inferred northwestward extension, *in* Anderson, T.H., Nourse, J.A., McKee, J.W., and Steiner, M.B., eds., *The Mojave-Sonora megashear hypothesis—Development, assessment, and alternatives: Geological Society of America Special Paper 393*, p. 51–95.
- Beikman, H.M., Haxel, G.B., and Miller, R.J., 1995, Geologic map of the Tohono O’Odham Indian Reservation, southern Arizona: US Geological Survey Miscellaneous Geologic Investigations Map I-2017, scale 1:125,000, 2 sheets.
- Campbell, P.A., and Anderson, T.H., 2003, Structure and kinematics along a segment of the Mojave-Sonora megashear—A strike-slip fault that truncates the Jurassic continental margin of southwestern North America: *Tectonics*, v. 22, no. 6, p. 16-1–16-21.
- Haxel, G.B., Tosdal, R.M., May, D.J., and Wright, J.E., 1984, Late Cretaceous and early Tertiary orogenesis in south-central Arizona—Thrust faulting, regional metamorphism, and granitic plutonism: *Geological Society of America Bulletin*, v. 95, p. 631–653.
- Tosdal, R.M., Haxel, G.B., Anderson, T.H., Connors, C.D., May, D.J., and Wright, J.E., 1990, Highlights of Jurassic, Late Cretaceous to early Tertiary, and middle Tertiary tectonics, south-central Arizona and north-central Sonora, *in* Gehrels, G.E., and Spencer, J.E., eds., *Geologic excursions through the Sonoran Desert region, Arizona and Sonora: Arizona Geological Survey Special Paper 7*, p. 76–88.